A Magnetic Susceptibility Logger for Archaeological Application

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Investigations of magnetic susceptibility have been used to (1) define sites, activity areas, features, buried soils, and cultural layers, (2) build and correlate stratigraphic sequences, and (3) understand site-formation and postdepositional processes. Archaeologists are limited in these endeavors, however, by the instruments available for field studies of susceptibility. A prototype instrument developed for archaeological application logs volume magnetic susceptibility down a small-diameter (ca. 2.2 cm) core-hole made with a push-tube corer. Measurements can be made rapidly, approximately 10 times faster than collecting samples either by coring or from an exposed section, to depths of 1.6 m below the surface. The prototype logger was field-tested on a mid-Holocene stratigraphic section in southeastern North Dakota where it clearly distinguished various soils and sediments, including a buried occupation layer.

INTRODUCTION

The magnetic susceptibility of soils and sediments is dependent on the composition, concentration, and grain size of the magnetic minerals that they contain (Banerjee, 1981; Thompson and Oldfield, 1986). Susceptibility contrasts can be used to identify, map, and correlate soil horizons, sedimentary sequences, and cultural layers. Susceptibility studies may be applied in conjunction with other soil magnetic techniques to provide information on the processes responsible for the formation of sites, activity areas, and features; to document postdepositional processes of erosion and sedimentation; and to understand climate variations in soil-forming regimes within archaeological contexts. As part of a special issue of *Geoarchaeology*, Dalan and Banerjee (1998) reviewed the current status and potential of soil magnetic studies, including magnetic susceptibility surveys, for archaeological application.

Despite the promise of soil magnetic research, susceptibility studies are only infrequently part of North American archaeological work. One reason for this may be limitations in available instrumentation. In those susceptibility surveys, the instruments usually used are the Geonics EM38 and two probes manufactured by Bartington Instruments. The Geonics EM38 effectively investigates the susceptibility of the top 0.5 m of soil. The Bartington Instruments MS2D and MS2F probes have effective penetration depths of ca. 10 and 1 cm, respectively. Even when all

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of these instruments are used in combination, they allow only a very limited range of shallow depths to be investigated.

Data on the variation of susceptibility with depth are usually obtained in the laboratory using samples collected by coring or from exposed sections or excavations. This approach has two advantages: (1) It has the potential to provide a detailed record of changes in mass magnetic susceptibility; and (2) other magnetic properties can be measured on these same samples. Yet there is also a significant disadvantage: collecting and packing samples is very time-consuming.

A susceptibility logger built with the assistance of a Technology Transfer Grant from the National Center for Preservation Technology and Training provides an alternative for obtaining this information. This instrument measures volume magnetic susceptibility down a core-hole (ca. 2.2 cm diameter) made using a standard Oakfield corer. The logger was built by rehousing a Bartington Instruments MS2F probe, calibrated to allow the calculation of absolute susceptibility values, and tested on a Middle Holocene section in southeastern North Dakota.

The susceptibility logger allows the economic and relatively nondestructive mapping of vertical changes in magnetic susceptibility across archaeological terrains. It is ideal for identifying buried sites, activity areas, features, or cultural layers and for building and correlating stratigraphic sequences. Coupled with other soil magnetic studies, the susceptibility data may also be employed in investigations of site formation and postdepositional processes (Dalan and Banerjee, 1998).

METHODS AND MATERIALS

The components of the Bartington system used in this study include the coil-wound-core sensor of the MS2F probe, an electronics (i.e., oscillator) unit, and an MS2 susceptibility meter. The operating frequency of the sensor is 0.58 kHz.

As constructed, the prototype logger (Figure 1) consists of a "handle" or down-hole tube of ½ inch (1.27 cm) Schedule 40 PVC pipe. A housing, or support structure, for the sensor, machined from solid PVC stock, attaches to one end. Wires pass through the handle and emerge at the other end where they attach to the electronics unit. Coaxial cables connect the electronics unit to the MS2 meter. The total length of the probe is 1.76 m making it possible to log susceptibility to depths of 1.6 m.

The probe was calibrated using a doughnut-shaped tank fashioned from two concentric cylinders. The probe was lowered down the inner cylinder (having the same diameter as the core-hole), and the outer cylinder was filled with material of a known susceptibility within the range of susceptibilities that are found in archaeological soils and sediments. The calibration tank was 8 in. (20.32 cm) high with an outer diameter of 6 in. (15.24 cm). The tank was filled with a small amount (1%) of magnetite dispersed in silica. A relatively large-grained magnetite was used (15-μm Wright Type 042093). To prevent clumping, this was dispersed in a finer-grained silica (5-μm quartz silica). Grain sizes of the magnetite and silica were verified with a scanning electron microscope (SEM).

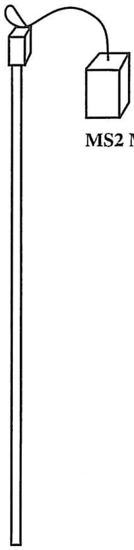

Figure 1(a). Schematic drawing of the prototype susceptibility logger.

The calibration exercise indicated that the probe measures approximately 85% of the value measured with a Bartington MS2B lab sensor on samples packed from the calibration mixture. Thus, the logger provides comparable sensitivity and can be used to investigate the same range of materials that can be measured with the lab sensor. In addition to taking an average of repeated readings in the center of the calibration tank to arrive at the calibration constant, a number of readings were taken as the susceptibility logger was moved up and down the calibration tank. Edge effects were noted at 3–4 cm from the bottom and top of the tank. Using the model of a magnetic dipole, an ellipse 6–8 cm long (3–4 cm up and down the core-hole) and 3–4 cm wide (1.5–2 cm laterally out from the core-hole in all directions) approximates the sensed volume. The response is not an averaged response over this volume; the response is much greater for materials in close proximity and falls off as the inverse cube of distance in all directions. Comparing several measurement sequences through the midsection of the tank indicated that values drifted 1% or less and thus that the probe is capable of producing replicable data.

RESULTS

Field trials evaluated the probe in an archaeological field situation replete with distinct stratigraphy. The trials were conducted at an Early Archaic site in southeastern North Dakota. The Rustad site (32RI775), remnants of which exist around the rim of a soil pit, has been subject to extensive archaeological excavation (Michlovic, 1996). The stratigraphic sequence, spanning the middle portion of the Ho-

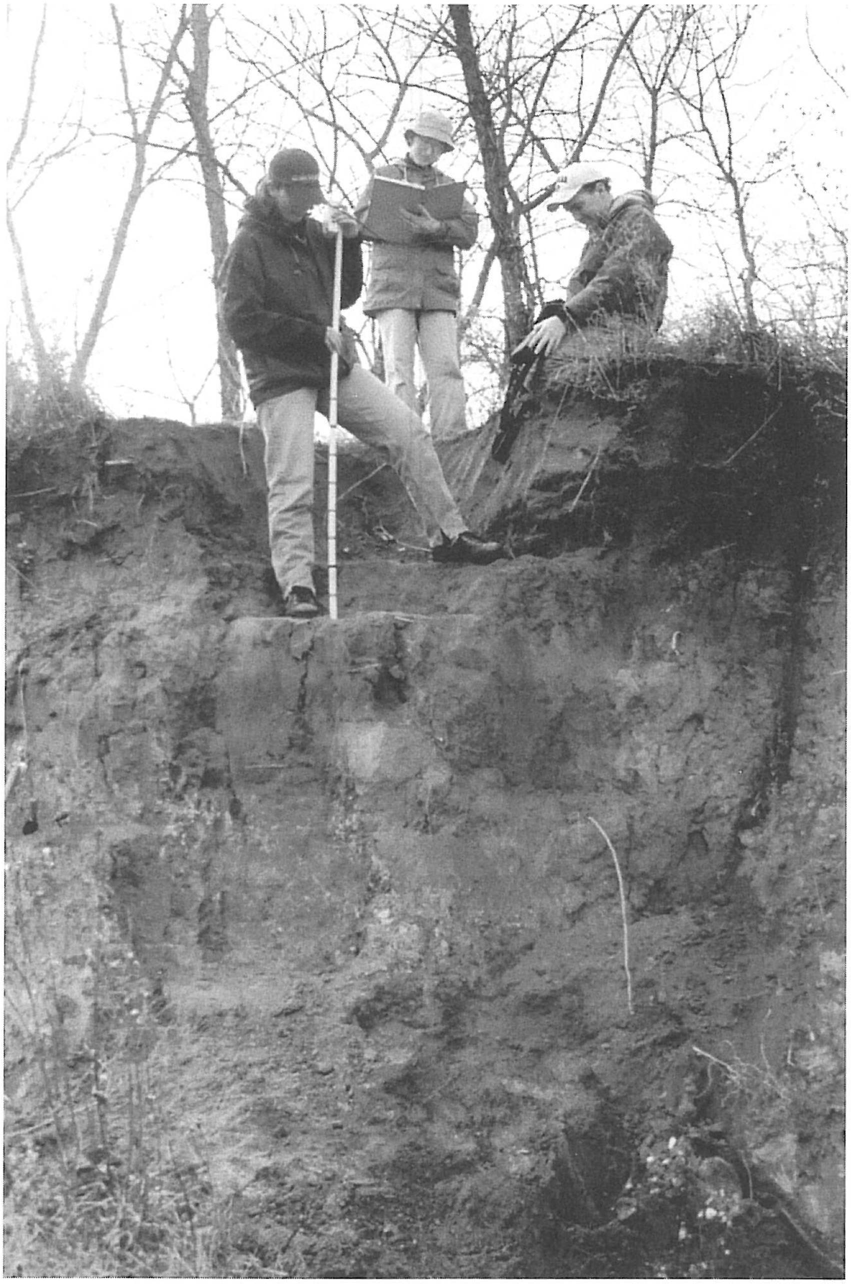

Figure 1(b). Field testing of the down-hole susceptibility logger at the Rustad site (32RI775), North Dakota. (Minnesota State University Moorhead students assisting with the field trials are, from left to right, Jenny Hawkinson, Naomi Rintoul, and Garrett Williams.)

locene, has been well described (Running, 1995). The stratigraphic sequence consists of a modern soil formed on eolian deposits underlain by alluvial fan deposits and then lacustrine sediments on whose surface is another well-developed soil. The alluvial fan sediments, deposited via mudflows from ca. 8000 to 5000 yr B.P., contain three buried soils. The Early Archaic cultural remains are associated largely with the oldest soil (Ab_3). The two lower soils (Ab_2 and Ab_3) are welded together in upfan positions. The field trials were conducted in an area where only the upper buried soil (Ab_1) and a single lower buried soil (Ab_3 or perhaps a merged $Ab_{2/3}$) were evident.

An Oakfield corer was used to make a hole approximately 15 cm back from the quarry wall. Prior to coring, approximately 80 cm of soil (i.e., the modern soil) were removed from the top of the quarry wall in order to focus the field trials on the middle Holocene portion of the stratigraphic section. Coring extended to ca. 1 m in depth below this truncated surface. The upper buried soil (Ab_1) in the alluvial fan deposits, barely identifiable at this location, was about 20 cm below this surface. The lower buried soil (Ab_3) containing cultural debris was approximately 50 cm below the surface. The core material was collected and bagged in 3-cm-long segments. It was apparent that slight mixing of sediments occurred as the core barrel was repeatedly pushed into and brought out of the ground.

The probe was zeroed in air, lowered down the core-hole for measurement, and then zeroed again in air before the next measurement was taken. Readings were taken at 2 cm increments to a maximum depth of 98 cm. Reproducibility, as shown in a comparison of two sequences of measurements (Figure 2) is high. Slight differences between the two sets of readings represent the combined effect of drift and differences in positioning the probe in the core-hole.

The exposed face was then cleaned back to within 5 cm of the core-hole. Plastic (nonmagnetic) Althor P15 boxes (5.28 cc volume) were pushed into the cleaned face to form a continuous sample column extending from 2 cm (the top of the first box) to 101 cm (the bottom of the last box) below the surface.

The data from the field trials are presented in Figures 2–4. Figure 2 presents the two sequences of readings obtained with the logger. Mass magnetic susceptibilities (χ) are plotted in Figure 3. Normalization by mass can only be accomplished with the collected samples. Volume susceptibilities are plotted in Figure 4. Figure 4 compares the average of the two logger sequences presented in Figure 2 with the volume susceptibilities gained from the core and column samples.

Figure 4 indicates that the logger provides reasonable data, both in terms of absolute numbers and in terms of patterns. The numbers are not exact, nor would we expect this, because of differences in the response volume of the logger as compared to the 5.28 cc volume samples of the column and the 3 cm core segments.

Comparing volume susceptibilities obtained with the logger to those calculated from the column samples, it appears that the calibration constant (the number calculated in calibration trials to convert instrument readings to absolute volume susceptibility values) is reasonable but perhaps a little high (yielding susceptibilities from 0.0001–0.0002 over the column values). An inspection of core volume

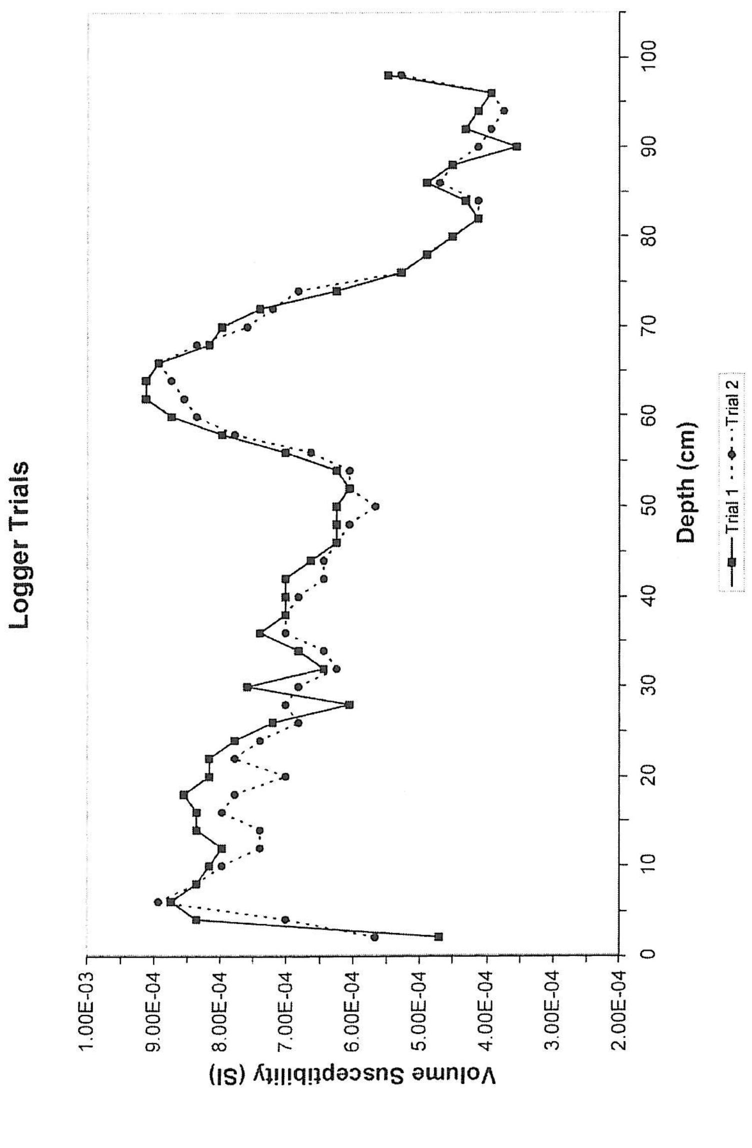

Figure 2. Comparison of two sequences of measurements taken with the down-hole susceptibility logger at the Rustad site.

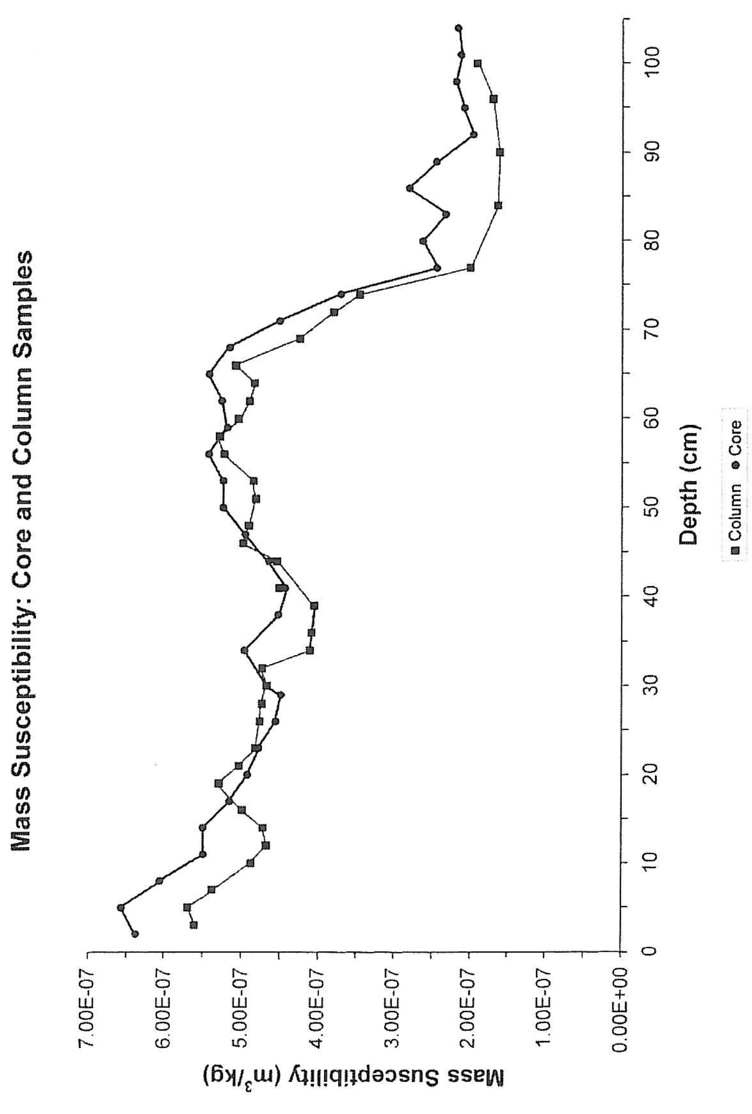

Figure 3. Mass magnetic susceptibility for column and core samples collected from the Rustad site. Core samples were collected in 3 cm segments while making the core-hole for the susceptibility logger and packed in P15 boxes in the lab. Column samples were obtained by pushing P15 boxes directly into a cleaned face located 5 cm from the core-hole. All samples were measured on a Bartington MS2B sensor (0.465 kHz setting) and normalized by mass.

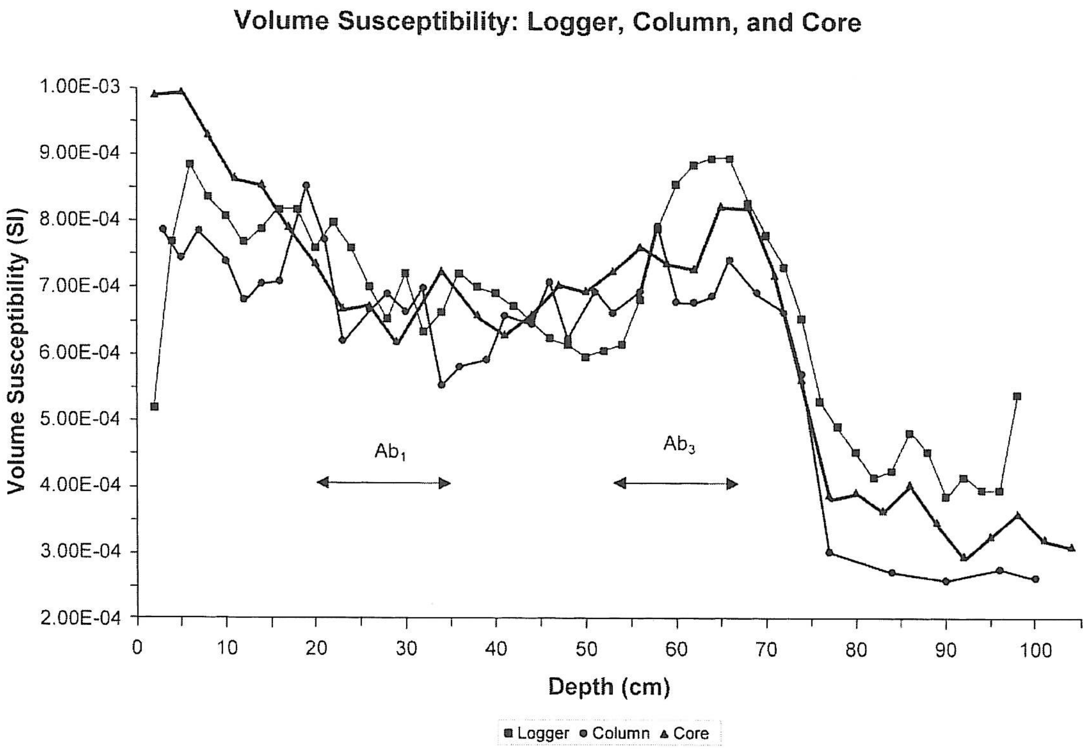

Figure 4. Comparison of volume magnetic susceptibilities obtained with the logger, the column, and the core. The logger curve represents an average of the two sets of measurements presented in Figure 2. The approximate location of the two buried soils located within the alluvial fan deposits was gained by a quick visual identification of the cleaned face. Eolian deposits are located above Ab_1 and lacustrine deposits below Ab_3.

susceptibilities, however, suggests that variations between the soils on the exposed face and those surrounding the core-hole may account for these differences. As the core samples were disaggregated and then repacked, it is best to look at the normalized mass magnetic susceptibility values to see if this might be the case. Indeed, as shown in Figure 3, these values do suggest that lateral changes in susceptibility may account for discrepancies between the column and logger values.

The most accurate and detailed record of susceptibility changes are the mass magnetic susceptibilities gained from the column samples (Figure 3). The logger measurements, however, run a close second. Certainly the logger curve is a better approximation of the column χ record than is the core sediments curve. This is most certainly due to the mixing of sediments as the core barrel is repeatedly moved up and down the core-hole but also a result of collecting and repacking core samples gained over 3 cm increments.

Compared to the P15 samples, the logger effectively smooths the data. In some ways, this built-in despiking of the data is helpful, aiding in the recognition of layers as it did for the buried cultural soil (Figure 4). Perhaps smoothing was not so advantageous, however, in the case of Ab_1. The upper buried soil does not show up well in the logger data, although it is distinct on the χ curve gained from the column samples. This soil layer is not associated with archaeological deposits and hence does not have as strong a signature. It is not visibly as distinct as the lower buried soil (Ab_3). Also, this soil is not visibly as distinct at this location as it is farther north along the quarry wall. As the core samples do not clearly delimit this layer, it may be even more weakly expressed back from the face where the logger was used.

It takes much time to collect and prepare P15 boxes. We were fortunate at the Rustad site that we could directly push the P15 boxes into the exposed face. In many cases, this would not be possible, and the estimate provided below would have to be lengthened. To clean and prepare the face, label the boxes, sample the 100 cm column, and measure the samples took about 2 h and 45 min. To collect, pack, and measure the core samples took about 4 h and 45 min. Using the prototype instrument, logging this same section took only 20 min. Adding to this the time to make the hole yields a total time of 25 min, 7–11 times faster than the more traditional methods.

CONCLUSIONS

The down-hole susceptibility logger greatly expands current capabilities for investigating magnetic susceptibility across archaeological terrains. It allows detailed field exploration of susceptibility with depth. The field and calibration trials indicate that the logger is a stable, reliable instrument that is capable of measuring susceptibility variations of archaeological interest. Layers of 3–4 cm, if not relatively weak in susceptibility contrast, may be distinguished. Coupled with aboveground instrumentation designed to map lateral variations in susceptibility, the logger provides a rapid, relatively nondestructive means of identifying, mapping, and correlating cultural strata, soil horizons, and stratigraphic sequences and for identifying and mapping both surface and buried sites, activity areas, and features.

The logger serves as a needed interface between lateral surveys of susceptibility and laboratory soil magnetic studies. To fully interpret field survey data, an understanding of changes in susceptibility throughout the soil column is crucial. This is what the logger provides. Also, in comparison to instruments like the EM38, the logger measures a volume of material more comparable to that studied using laboratory sensors. In addition, samples may be collected from the core-hole as part of the logging operation for use as controls or for investigating additional magnetic properties back in the laboratory. These laboratory studies may be directed toward understanding the processes responsible for the formation of identified features or layers, allowing archaeologists to address questions regarding function, postdepositional processes, and past climatic and environmental regimes.

A critical advantage of the susceptibility logger is that it is fast. Unless an archaeologist is fortunate enough to have an exposed section or unless there are open excavations, instruments like the Bartington MS2D and MS2F probes cannot be used. Samples are traditionally taken through coring and laboratory measurement. The logger allows a more accurate measurement of vertical variations in susceptibility at a rate that can be more than 10 times faster than this traditional method. Not only does greater speed save money, but it may also permit measurements to be made over a larger area or at a much higher spatial resolution.

In addition to its speed, another advantage of the logger is its ability to interface with the Bartington MS2 meter and hence the Bartington suite of sensors. Investing in the logger and MS2 meter provides an expandable system that may later be used to operate the various Bartington laboratory and field coils. Conversely, the logger may be used by anyone who already owns a Bartington MS2 meter. Not only is the susceptibility logger a useful tool for archaeologists, but it also has the potential to be used by others who use small diameter corers to investigate near-surface layering of soils and sediments.

A caveat arose from an attempt to use the logger at the National Park Service sponsored course "Recent Advances in Archaeological Propsection Techniques" held in Tucson, Arizona in April 2000. Silty and very dry soils made it impossible to make a push-tube core hole. Thus, application of this technology might be severely limited in certain parts of the world just due to the inability to use a push-tube corer.

It is my hope that a version of this instrument will be made commercially available. Based on research to date, I suggest only minimal modifications to the design of the prototype logger. The main problem that I have encountered has not been related to performance but to transport: The packing case measures 178 cm (70 inches) long, making it unwieldy. A segmented or telescoping shaft would solve this problem.

The susceptibility logger allows a new avenue for the relatively nondestructive exploration of archaeological deposits. Employed as part of site assessment, as part of site interpretation, and in studies devoted to site conservation and restoration, it has the potential to be a very useful addition to an archaeologist's tool kit.

I am indebted to the late Tony Clark, whose pioneering efforts to design a bore-hole susceptibility instrument for archaeological application I have attempted to carry forward. The success of this endeavor is due in large part to advice and expertise offered by Jim Marvin, Institute for Rock Magnetism, University of Minnesota. I would also like to thank Bartington Instruments for their interest in and assistance with this project. This research was supported by a grant from the National Park Service and the National Center for Preservation Technology and Training. The contents of this publication are solely the responsibility of the author and do not necessarily represent the official position or policies of the National Park Service or the National Center for Preservation Technology and Training. Jenny Hawkinson prepared Figures 1(a) and 2–4 . Many thanks are due to Mike Jackson, Bill Johnson, and Bruce Bevan for their comments on a draft version of this article.

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